



Lights in the Deep

Focus

Bioluminescence

Grade Level

9-12 Biology/Chemistry (Note: Parts of this activity can be easily modified for Grades 5-8)

Focus Question

How do animals produce and use light in the deep ocean?

Learning Objectives

Students will be able to describe, compare, and contrast bioluminescence, fluorescence, phosphorescence, and chemiluminescence.

Students will be able to explain the role of three major components of bioluminescent systems.

Students will be able to explain how at least three organisms use bioluminescence.

Students will be able to discuss at least three practical applications of knowledge about bioluminescence and how this knowledge may benefit humans.

Additional Information for Teachers of Deaf Students

In addition to the words listed as key words, the following words should be part of the vocabulary list.

Atoll

Nautical

SCUBA

Exploration

ROV

Corals

Adaptation

Bioluminescence

Mating

Prey

Near infrared

Luciferase

Photoprotein

Emitted

Internal ampoule

The key words are integral to the unit but will be very difficult to introduce prior to the activity. They are really the material of the lesson. There are no formal signs in American Sign Language for any of these words and many are difficult to lipread. Having the vocabulary list on the board as a reference during the lesson will be extremely helpful. This activity may require a bit more time than is called for in the activity to complete.

Have the examples of bioluminescent organisms pulled up on the web and ready before class begins.

The definitions of bioluminescence, phosphorescence, and chemiluminescence included in the Background Information should be copied and used as a handout. This activity is very difficult and Steps #1, #2 and #3 of the Learning Procedure should be conducted as one large group. In Step #4, each student should research one organism. Then, as a class, they should find at least one example of how knowledge about bioluminescence is

being used in ways that are directly important to humans. Extension #1 should be done as a homework assignment. Information listed in the Background Information on the jellyplants for Mars exploration should be eliminated, unless the class has a particular interest or a great deal of additional time.

MATERIALS

- ☐ Light sticks, one for each student group
- ☐ Ultraviolet light source (may be shared among student groups)
- ☐ Fluorescent minerals or other fluorescent materials, such as laundry detergent
- ☐ Glow-in-the-dark modeling clay
- ☐ Cardboard boxes with small holes cut out for viewing objects in the dark
- ☐ (OPTIONAL, if you wish to include the "Jellyplant" project), background materials can be found at <http://www.thursdaysclassroom.com/01jun01/pdf/corner.pdf>

AUDIO/VISUAL MATERIALS

None

TEACHING TIME

Introduction: one-half to one 45-minute class period

Oral presentations and discussion: one-half to one 45-minute class period

Group research and writing: 1 - 2 hours

Optional Work on "jellyplants": depends on extent of activities; may extend over several weeks if you have students duplicate experiments conducted on the International Space Station

SEATING ARRANGEMENT

Groups of four students

MAXIMUM NUMBER OF STUDENTS

32

KEY WORDS

Bioluminescence
Fluorescence
Phosphorescence
Chemiluminescence
Photoprotein
Luciferin
Luciferase
Reporter gene
Thale cress

BACKGROUND INFORMATION

Nearly 70% of all coral reefs in U.S. waters are found around the Northwestern Hawaiian Islands, a chain of small islands and atolls that stretches for more than 1,000 nautical miles (nm) northwest of the main Hawaiian Islands. While scientists have studied shallow portions of the area for many years, almost nothing is known about deeper ocean habitats below the range of SCUBA divers. Only a few explorations have been made with deep-diving submersibles and remotely-operated vehicles (ROVs), but these have found new species and species previously unreported in Hawaiian waters. These islands are regularly visited by Hawaiian monk seals, one of only two species of monk seals remaining in the world (the Caribbean monk seal was declared extinct in 1994). Waters around the Northwestern Islands may be an important feeding area for the seals, which appear to feed on fishes that find shelter among colonies of deep-water corals. These corals are also of interest because they include several species that are commercially valuable for jewelry. The possibility of

discovering new species is important because of commercial potential as well as scientific interest, since some of these species may produce materials of importance to medicine or industry.

Organisms that live in deep ocean habitats have a variety of adaptations that may be useful for various human activities. One of the best-known adaptations to life in the deep ocean is bioluminescence – the emission of visible light by living organisms. Many deep-sea organisms are capable of bioluminescence, and use it to attract food, to frighten predators, and as a communication system in mating and reproduction. Some fishes have a built-in night vision system in which they produce red light that allows them to find their prey with eyes that can see in the near-infrared region of the light spectrum.

More examples of bioluminescent organisms can be found on the Bioluminescence Web Page at <http://lifesci.ucsb.edu/~biolum/>.

Bioluminescence is not the same thing as fluorescence or phosphorescence, and it is important to know the differences among these processes. In fluorescence, energy is absorbed from a light source and then re-emitted at a longer wavelength. Since the re-emitted light cannot contain more energy than was received in the absorbed light, the re-emitted light must have a longer wavelength because light at longer wavelengths (toward the red end of the spectrum) contains less energy than light at shorter wavelengths (toward the blue end of the spectrum). So if blue light is received from a light source, fluorescence might be green or yellow; if green light is received, then the fluo-

rescence might be yellow or red.

Phosphorescence is similar to fluorescence, except that the re-emission of light takes place over a longer period of time, such as in the case of glow-in-the-dark signs.

Chemiluminescence is the production of light from energy provided by a chemical reaction. “Light sticks” are a familiar example of chemiluminescence. Bioluminescence is a type of chemoluminescence in which the chemical reaction that provides the energy for light production takes place inside an organism. The term “luminescence” is frequently encountered in articles about light production in natural systems. This term simply means “light-producing,” and does not refer to a specific process through which light is produced.

Bioluminescence typically requires at least three components: an organic molecule known as a luciferin which participates in a chemical reaction that releases energy; a source of oxygen (may be O_2 , but could also be hydrogen peroxide or a similar compound); and a protein catalyst known as a luciferase. In some organisms, these three components are bound together in a complex called a photoprotein. Light production may be triggered by the presence of ions (often calcium) or other chemicals. Some bioluminescent systems also contain a fluorescent protein that absorbs the light energy produced by the photoprotein, and re-emits this energy as light at a longer wavelength.

The chemiluminescent systems of light sticks is triggered by hydrogen peroxide (isolated in a thin glass ampoule inside the stick until the stick

is flexed, causing the ampoule to break), which reacts with an oxalic phthalate ester. The ester is oxidized to form phenol and carbon dioxide. An intermediate product of this reaction is a high-energy molecule that energizes a dye also contained in the light stick. The dye molecules subsequently release this additional energy as a photon of light, causing a glow, the color of which depends upon the specific dye used in the light stick system.

In addition to scientific interest in the role of bioluminescence in the functioning of deep-sea communities, knowledge about bioluminescent systems is being used to design living systems for the exploration of other planets. Small mustard plants known as thale cress (*Arabidopsis thaliana*) are being genetically modified to act as living sensors that can report on environmental conditions on the surface of Mars. The mustard plants have well-developed sensing systems that can detect potentially stressful conditions such as low oxygen, high radiation levels, water scarcity, and extremes in air pressure or temperature. These sensing systems trigger physiological responses in the plants that allow them to better adapt to environmental stress. To make use of these systems, scientists are adding “reporter” genes to the mustard’s own sensor genes. The reporter genes come from a jellyfish (*Aequorea victoria*) that has a bioluminescent system consisting of a photoprotein coupled with a green fluorescent protein. When the genetically-modified mustard plants encounter a particular type of stress, their sensing systems trigger the bioluminescent system and cause a green glow to be emitted, sort of like an alarm light.

To use the “jellyplants” for Mars exploration, seeds for the plants would be carried to Mars aboard a small space vehicle which would land on the planet’s surface, collect Martian soil, then germinate the seeds to grow in a miniature greenhouse. Sensors attached to the greenhouse would detect glows from the growing plants that would provide information about stressful conditions encountered by the plants.

This activity focuses on the basic process of bioluminescence, and ways in which this process is utilized by deep-sea organisms. Optionally, you may also want to include activities related to the development of “jellyplants” for interplanetary exploration.

LEARNING PROCEDURE

1. Introduce the location of the Northwestern Hawaiian Islands, and point out some of the features that make this area important (discussed above). Emphasize that much of the Northwestern Hawaiian Islands Expedition will explore areas that have never been visited before, particularly the deep ocean environments surrounding these islands. Have students describe what they believe the deep-sea environment is like. Ask students what challenges to life might be posed by total darkness (photosynthesis is not possible; not possible for predators to locate food organisms by sight, unless . . .), leading to the advantages that might be associated with a self-generated source of light.

Lead a discussion of bioluminescence, comparing and contrasting this process with fluorescence, phosphorescence, and chemilumi-

nescence. Describe the overall reactions that occur in bioluminescence and the chemiluminescence of light sticks. Point out that some bioluminescent systems also have an accessory protein that fluoresces in addition to the photoprotein.

2. Provide each student group with a light stick, ultraviolet light source, glow-in-the-dark modeling clay, and fluorescent minerals or other fluorescent materials (such as laundry detergent, which has additives that makes clothes look whiter by absorbing ultraviolet light energy from sunlight then emitted as blue fluorescent light). Instruct students NOT to break their light sticks until told to do so. Have each group examine their materials; first, in near-total darkness (you may want to use cardboard boxes with small holes cut out for viewing), then in darkness under ultraviolet light. Finally, have students activate their light sticks by flexing the stick to break the inner glass ampoule. Students should record their observations at each stage, and classify any observed light emission as fluorescence, phosphorescence, or chemiluminescence.
3. Have each group present their results, and lead a discussion of the light-emitting processes observed. Be sure students understand the distinction between these processes, and how bioluminescent systems might include both chemiluminescence and fluorescence. Students may have observed that the light sticks glowed when placed under the ultraviolet light (depending on the specific characteristics of the ultraviolet light and the light stick). If this was observed, they should recognize that this light results from fluores-

cence, while the light emitted from the light stick after the internal ampoule is broken is the result of chemoluminescence.

4. Have each group research at least one of the following organisms that use bioluminescence:
 - Anglerfish
 - Fire Shooter Squid
 - Black Dragonfish
 - Dinoflagellates
 - Copepods
 - Euphausiids
 - Comb Jellies
 - Cookie Cutter Shark

Each group should also find at least one example of how knowledge about bioluminescence is being used in ways that are directly important to humans. The Internet resources listed below are a good start for these examples.

Groups should make brief written and verbal presentations of their research results, highlighting what is known about the chemistry of the organism's bioluminescent system, how the organism uses bioluminescence, and how knowledge of these systems may be of benefit to humans.

5. (OPTIONAL) Describe the "jellyplants" project, and how a bioluminescent system is being used to create plants that can report specific types of environmental stress. Visit <http://www.thursdaysclassroom.com/01jun01/pdf/corner.pdf> for an article on the project, suggestions for class activities, and links to other sites.

THE BRIDGE CONNECTION

www.vims.edu/bridge/plankton.html

THE “ME” CONNECTION

Have students write a short essay on how research on deep-sea bioluminescent organisms could prove to be of direct personal benefit. This does not have to be based on actual discoveries that have already been made (though this is fine, too), but should be what MIGHT happen, and what events or discoveries would link a bioluminescent process to their own life.

CONNECTIONS TO OTHER SUBJECTS

Chemistry, English/Language Arts

EVALUATION

Develop a grading rubric that includes oral presentations in Steps #3 and #4, and the written report in Step #4.

EXTENSIONS

1. Have students research green fluorescent protein (GFP) and report on other ways this bioluminescent product is being used in scientific and medical research.
2. Have students report on the molecular structure of green fluorescent protein (GFP) or another component of a bioluminescent system.
3. Have students report on reporter genes, including examples of how these are being used in scientific and medical research.

RESOURCES

<http://oceanexplorer.noaa.gov> – Follow the Northwestern Hawaiian Islands Expedition as documentaries and discoveries are posted each day for your classroom use.

<http://www.biolum.org/> – Harbor Branch Oceanographic Institution website on bioluminescence

<http://lifesci.ucsb.edu/~biolum/> – The Bioluminescence Web Page

<http://www.biochemtech.uni-halle.de/PPS2/projects/jonda/> – Lots of information about green fluorescent protein

http://science.nasa.gov/headlines/y2001/ast01jun_1.htm/ – Starting point for information about the “jelly-plants” project.

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Chemical reactions
- Interactions of energy and matter

Content Standard C: Life Science

- Matter, energy, and organization in living systems

*Activity developed by Mel Goodwin, PhD,
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